CONFIGURATION OF THE GFDL FV DYNAMICAL CORE

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GFDL AM3 Summer School

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```
&fv_core_nml
    layout    = $fv_layout
    io_layout = $fv_io_layout
    npx       = 49,
    npy       = 49,
    ntiles    = 6,
    npz       = 48,
    n_split   = 8,
    a2b_ord   = 4,
    adjust_dry_mass = $adjust_dry_mass,
    consv_te = 0.7,
    fill = .true.
    print_freq = 0,
    grid_type = 0,
    old_divg_damp = .true.,
    nord = 0,
    dddmp = 0.0,
    d2_bg = 0.0075,
    d4_bg = 0.00,
    tau = 0.
/

&coupler_nml
    …
    dt_atmos = 1200
/
```

Discussed by computing services

Model resolution

Time step

Damping

Dynamics

Diagnostics

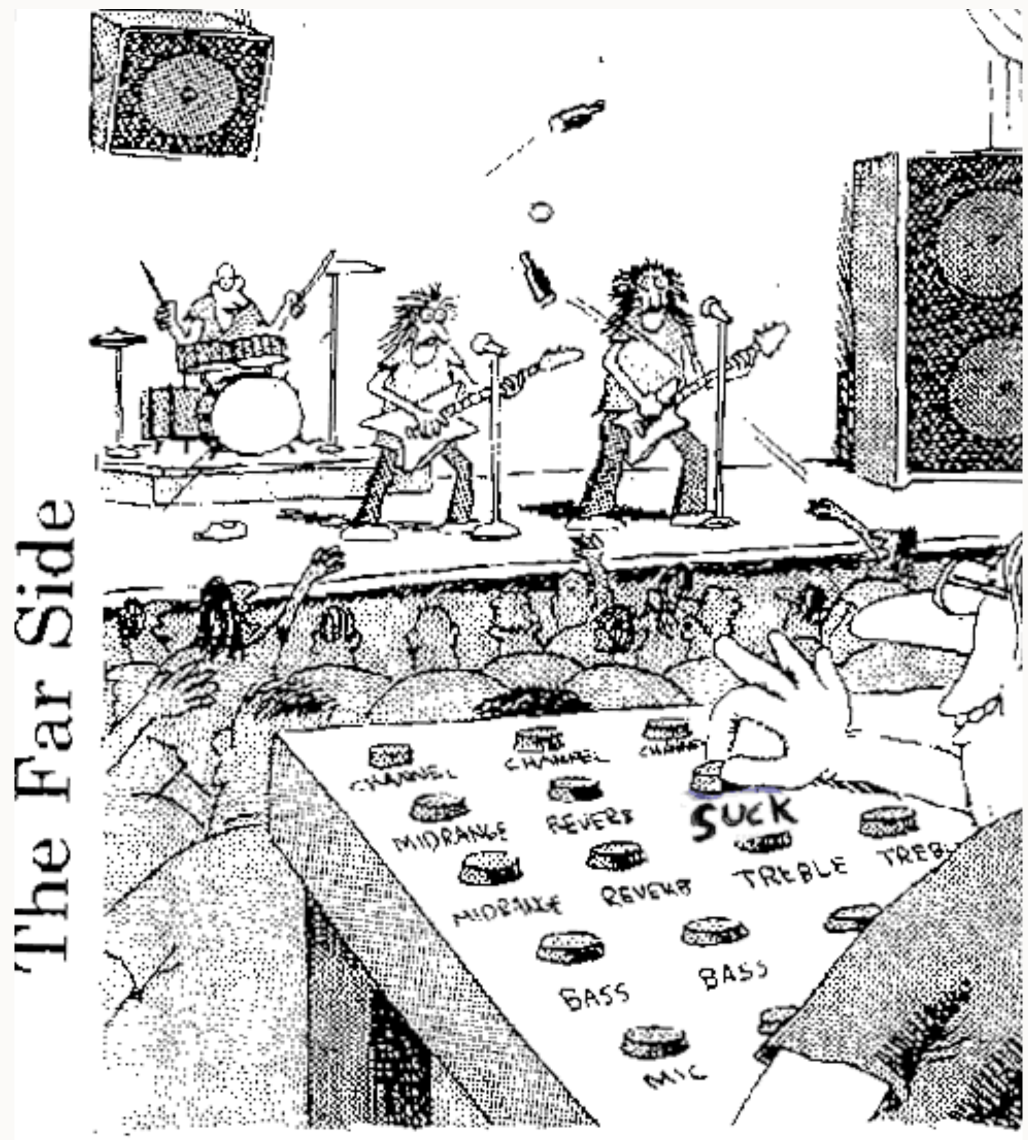
Grid options

NAMELIST DEFAULTS

- A options which is not specified in `fv_core_nml` is assigned a default value (see fv_arrays.F90 or fv_control.F90 for more information)
  - Some options **must** be specified:
    - `npx, npy, npz`
    - `ntiles = 6`
    - `layout`

WARNING

- If you don't know what an option does, don't mess with it
- Unfortunately no `do_what_I_want = .true.` option



Raymond's last day as the band's sound technician.

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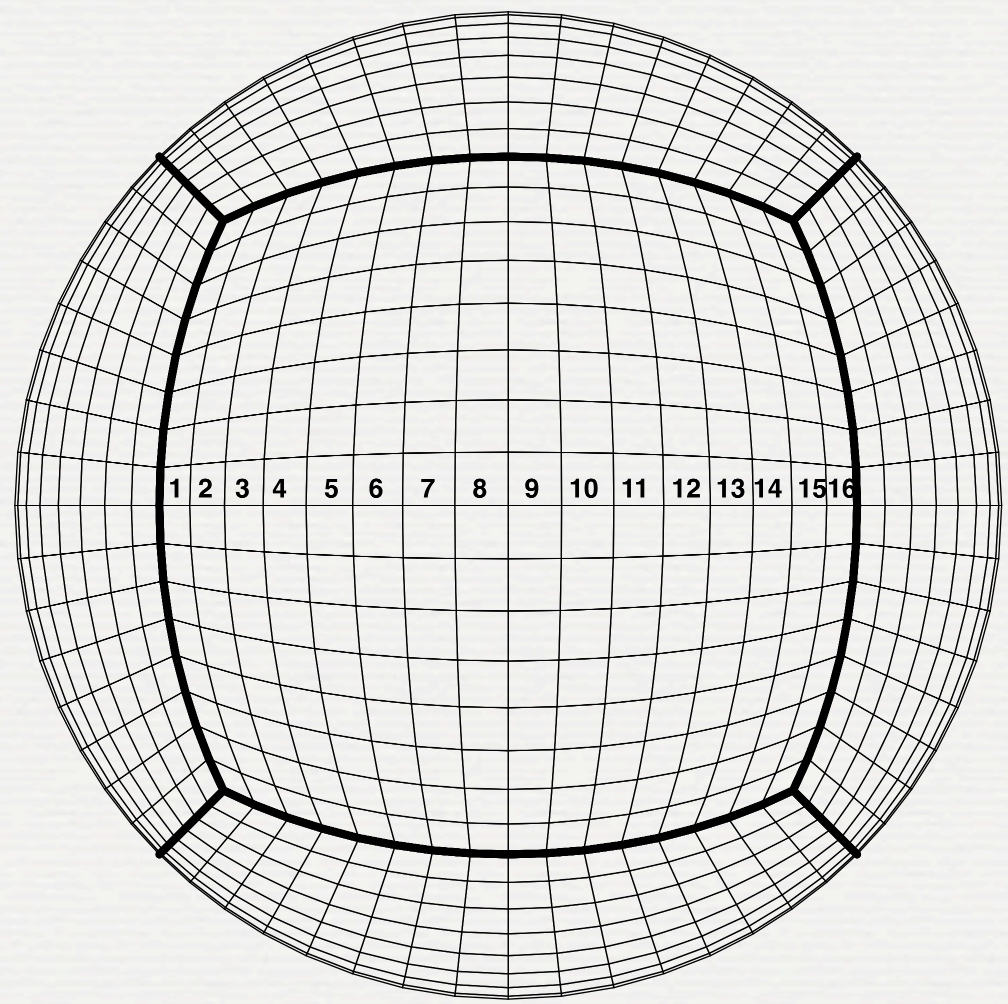
MODEL RESOLUTION

- `npx`, `npy`: number of **grid corners** across a cube face
- `npx`-1 **grid cells** across a cube face
- `npx` and `npy` must be the same
- `npx-1` and `npy-1` ideally divisible by `layout`

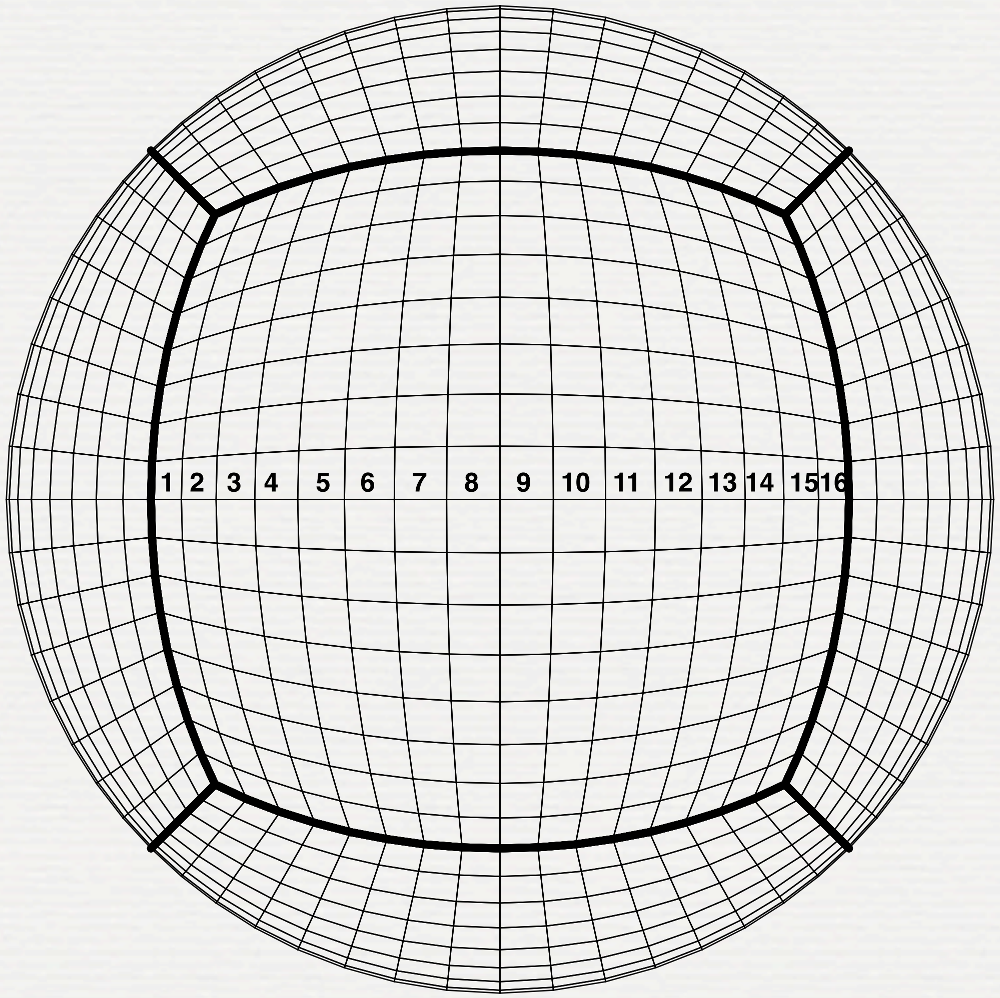


c16 grid

`npx` = `npy` = 17

MODEL RESOLUTION

- Average cell width of a cN grid is roughly 10000 km / N
  - $2\pi R = 40000$ km
  - 4 faces around circle
- Ratio between max and min cell width is $\sqrt{2} \approx 1.41$



c16 grid

$\Delta x \approx 625$ km

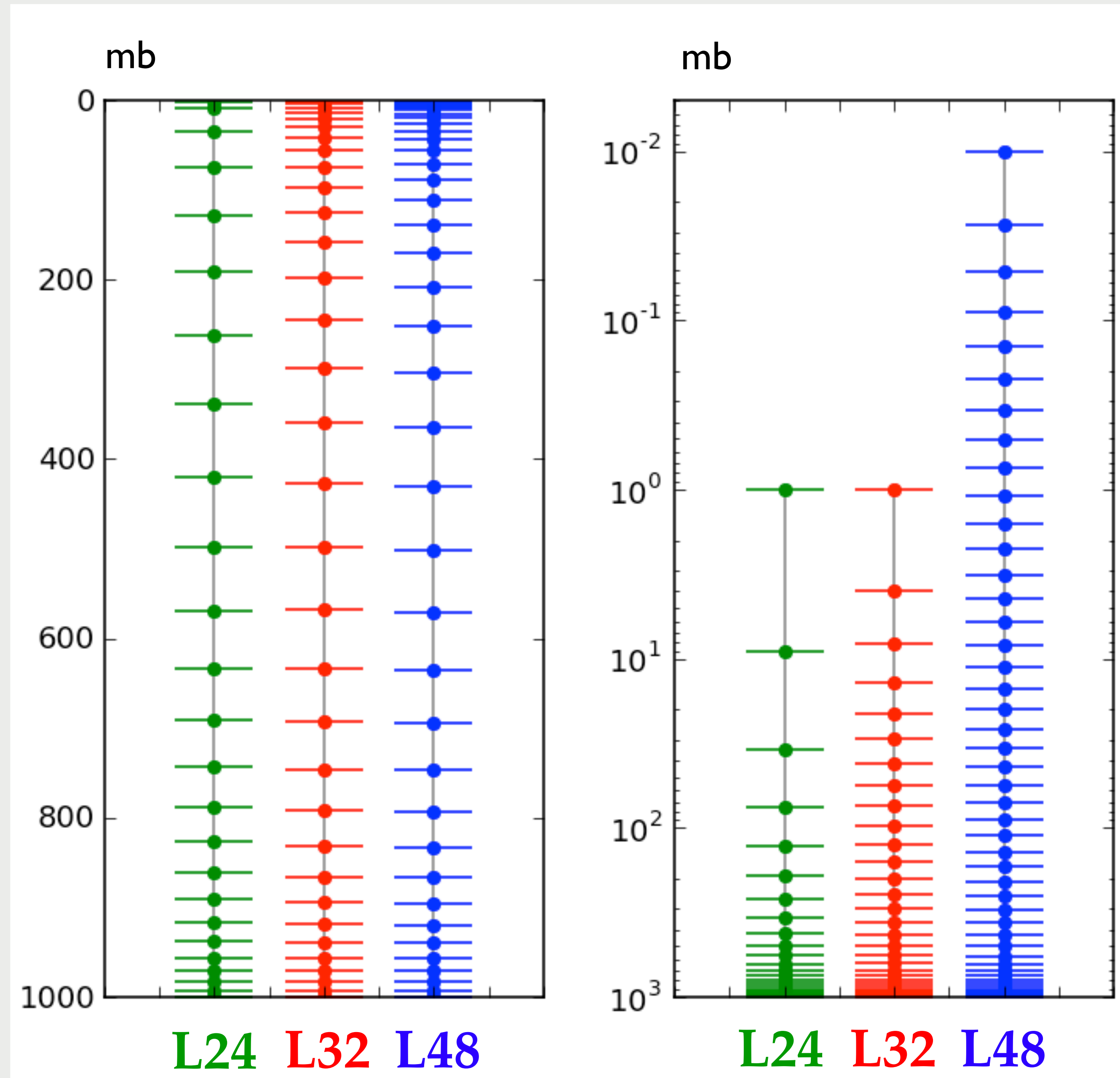
500 to 750 km

MODEL RESOLUTION

Grid	Avg. Δx	Equiv. ΔΦ
c16	625 km	5.5°
c48	210 km	2°
c90	110 km	1°
c180	55 km	0.5°
c360	25 km	0.25°
c720	12 km	0.125°
c2560	4 km	0.35° (2′)

VERTICAL RESOLUTION

- `npz`: number of vertical layers
  - AM2: 24
  - AM3: 48
  - HiRAM: 32
- Layer thicknesses are pre-defined for each `npz`



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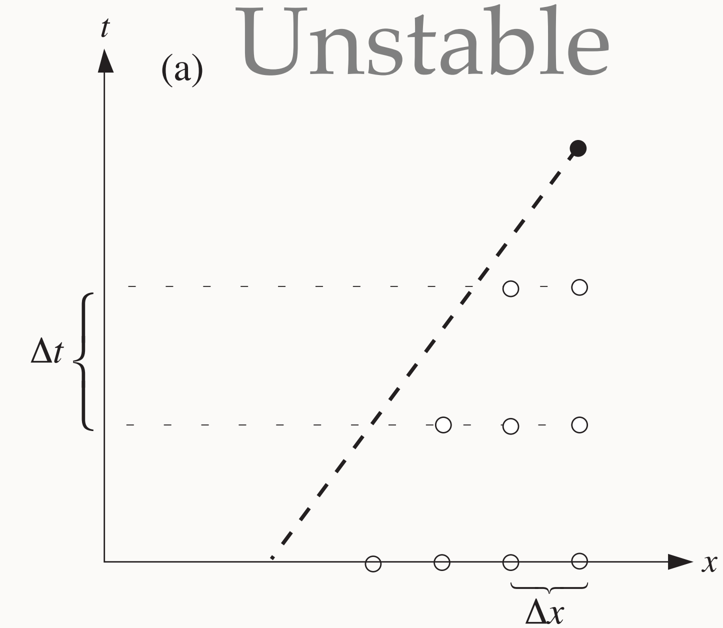
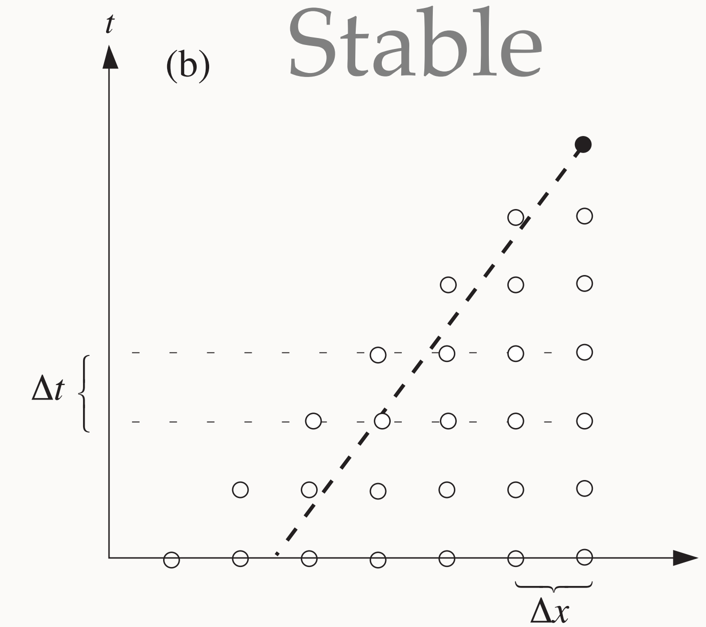
TIMESTEPS AND THE CFL RESTRICTION

- Courant number: $C = U\Delta t/\Delta x$
- **C**ourant-**F**riedrichs-**L**ewy condition: stable only if signals in the exact PDE do not leave the numerical domain of dependence
- For the hydrostatic FV Core $C < 1$ is required

Unstable



Stable



Durran, 2009

TIME STEPPING IN THE FV CORE

- `dt_atmos`: physics timestep (except radiation)
- `k_split`: number of vertical remappings per physics timestep
  - Usually `1` (default) or `2`
- `n_split`: number of dynamical timesteps per `k_split` step
  - Δt = `dt_atmos/(k_split*n_split)`

CHOOSING YOUR TIMESTEP: N_SPLIT

- `n_split = dt_atmos/`(Δt*`k_split`)
- Ideally:
  `n_split =`$\lceil$`dt_atmos`*U_{max}/(Δx_{min}*`k_split`)$\rceil$
  - **However**…nonlinearity and gravity wave propagation require a smaller Courant number
  - U_{max} can be quite large in the stratosphere!

A BEST FIRST GUESS

- Set `n_split = 0` to get an automatic guess from the model
  - Look in `stdout` for the selected `n_split`
- May need to tweak value anyway
  - If your model crashes, try increasing `n_split` first (**instead** of decreasing `dt_atmos`)

EXAMPLE #1: C48

- $\Delta x_{avg} = 210$ km
- If `dt_atmos` = 1200 s and `k_split` = 1 (default):

```
  starting             1  OpenMP threads per MPI-task
 For k_split (remapping)=           1
n_split is set to 05 for resolution-dt=0049x0049x6- 1200.000
Using n_sponge : 00
Using non_ortho :       T
 Starting PEs :            96
 Starting Threads :            1
```

- $\Delta t = 1200$ s / 1 / 5 = 240 s
- $C \approx 200$ m/s * 240 s / (210 km * 0.8) ≈ 0.29

EXAMPLE #2: C720

- $\Delta x_{avg} = 12$ km
- If `dt_atmos` = 300 s and `k_split` = 2:

```
  starting            1  OpenMP threads per MPI-task
 For k_split (remapping)=           2
n_split is set to 09 for resolution-dt=0721x0721x6-  300.000
Using n_sponge : 00
Using non_ortho :       T
 Starting PEs :            96
 Starting Threads :            1
```

- $\Delta t = 300$ s / 2 / 9 = 17 s
- $C \approx 200$ m/s * 17 s / (12 km * 0.8) ≈ 0.35

TRACER SUB-CYCLING

- Tracers are advanced **after** completing `n_split` dynamical timesteps using the accumulated air mass fluxes
- Since tracer advection is linear and depends only on the wind speed, the Courant number can be closer to 1.
- By default (`q_split = 0`) the model computes the number of split tracer timesteps automatically:
  - $\max \{\sum_{\texttt{n\_split}} C\} + 1$

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    consv_te = 0.7,
    fill = .true.
    print_freq = 0,
    grid_type = 0,
    old_divg_damp = .true.,
    nord = 0,
    dddmp = 0.0,
    d2_bg = 0.0075,
    d4_bg = 0.00,
    tau = 0.
/

&coupler_nml
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- Discussed by computing services
- Model resolution
- Time step
- **Damping**
- Dynamics
- Diagnostics
- Grid options

DIVERGENCE DAMPING

- One of two means of noise control in FV Core
- `nord`: order of divergence damping
  - `nord = 0` : ∇^2 divergence damping
    - `d2_bg`: damping coefficient, default 0
  - `nord = 1`: ∇^4 divergence damping; more scale selective (default)
    - `d4_bg`: damping coefficient, default 0.16, maximum 0.25

UPPER SPONGE LAYER

- Top two layers are wave-absorbing layers, implemented through additional divergence damping and diffusive lower-order flux operators
  - `old_divg_damp = .true.` : From CMIP5 runs
  - `n_sponge = 0`: 2 layers with presets good for high-resolution simulations
    - (must have `old_divg_damp = .false.`)
  - `n_sponge = 1`: 2 sponge layers (default)
  - `n_sponge` > 1: `n_sponge` + 1 sponge layers

OTHER DAMPING PARAMETERS

- `tau`: strength of Rayleigh friction applied near top boundary; 0 by default
- `d_ext`: barotropic ("external") mode damping; 0.02 by default, maximum 0.25
- `d_con`: rate at which energy dissipated by divergence damping turned into heat, so as to better conserve energy. 0 by default; use at your own risk

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TRACER FILLING

- Positive-definite Lin & Rood tracer advection produces tiny negatives (10^{-25} and smaller)
- Set `fill = .true.` when it absolutely, positively **must** be positive
    - Negative filling is done in the **vertical** to avoid possibly having to reach across process domains

CONDENSATE LOADING

- The FV core uses the microphysical tracers to *explicitly* compute condensate loading of `nwat` species
  - `nwat = 3` by default, for three-phase AM3 microphysics
  - If using six-phase Lin microphysics set `nwat =` **6**
  - Don't want loading? Set `nwat = 0`

DYNAMICS PARAMETERS

- `beta`: time-centering parameter for pressure-gradient force
  - 0 by default; 0.4 may improve solution of gravity waves in the tropics
- `hord_tr`: tracer advection scheme
  - 12 by default: monotone and positive-definite
  - 13: positive-definite only, faster

DYNAMICS PARAMETERS

- `a2b_ord`: order of interpolation of pressure to corners for PGF; 4 by default
- `consv_te`: amount to correct total energy lost in dynamics and vertical remapping
    - 0 by default; 0.7 in full-physics simulations

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/
```

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PRINT_FREQ

```
     1          0
ZS max =   0.000000000000000E+000  min =   0.000000000000000E+000
PS max =    1015.00000000000       min =    1004.82291130741
Mean specific humidity (mg/kg) above 75 mb=  9.999999999999999E-006
Total surface pressure (mb) =    1014.99347525107
mean dry surface pressure =    1010.06551436790
Total Water Vapor (kg/m**2) =   50.2853151343074
ENG Deficit (W/m**2)=  0.0000000E+00
UA max =    19.1862477411642       min =   -19.5545697489168
VA max =    19.6695572008257       min =   -19.2094634974794
TA max =    301.987126680501       min =    201.007851200000
OM max =   0.000000000000000E+000  min =   0.000000000000000E+000
RH_sf (%) max =    84.1964443194992       min =    83.1611373517436
RH_3D (%) max =    84.1964443194992       min =   1.838996873108497E-006
PoTemp max =    1178.99543758473       min =    301.006081741117
sphum max =   2.075856765343869E-002  min =   9.999999999999999E-012
```

- Hours between diagnostic printout
  - 0 (default) for no output
  - Set to -1 to get output every timestep

DEBUGGING OUTPUT

- `fv_debug = .true.` prints out max/min at beginning and end of every call to the FV core
- `range_warn = .true.` prints warnings if model variables exceed reasonable bounds
- Both are `.false.` by default
- Any diagnostic output will slow down the model

INITIAL CONDITIONS

- Set `external_ic = .true.` to use external lat-lon data source given in `res_latlon_dynamics`
  - When initializing the model, set `adjust_dry_mass = .true.` to add the mass of water vapor to the initial mass to account for condensate loading
    - Automatically set in most scripts

INITIAL CONDITIONS

- When `external_ic = .true.`:
  - `ncep_ic = .true.` if using an NCEP or NCEP-compatible analysis or reanalysis
  - `diag_ic = .true.` if instead using a lat-lon FV core output file
    - Can also use `res_latlon_tracers` to initialize tracers with this option

BOUNDARY CONDITIONS

- Topography for FV core (and gravity wave drag) specified in `surf_map_nml`
- Specifying SSTs is done in `ocean_model_nml` and `amip_interp_nml`
- `nudge = .true.` uses input data in `res_latlon_dynamics` to nudge the solution to the analysis state

REFINED GRIDS: PRELIMINARY RESULTS

NESTED GRID

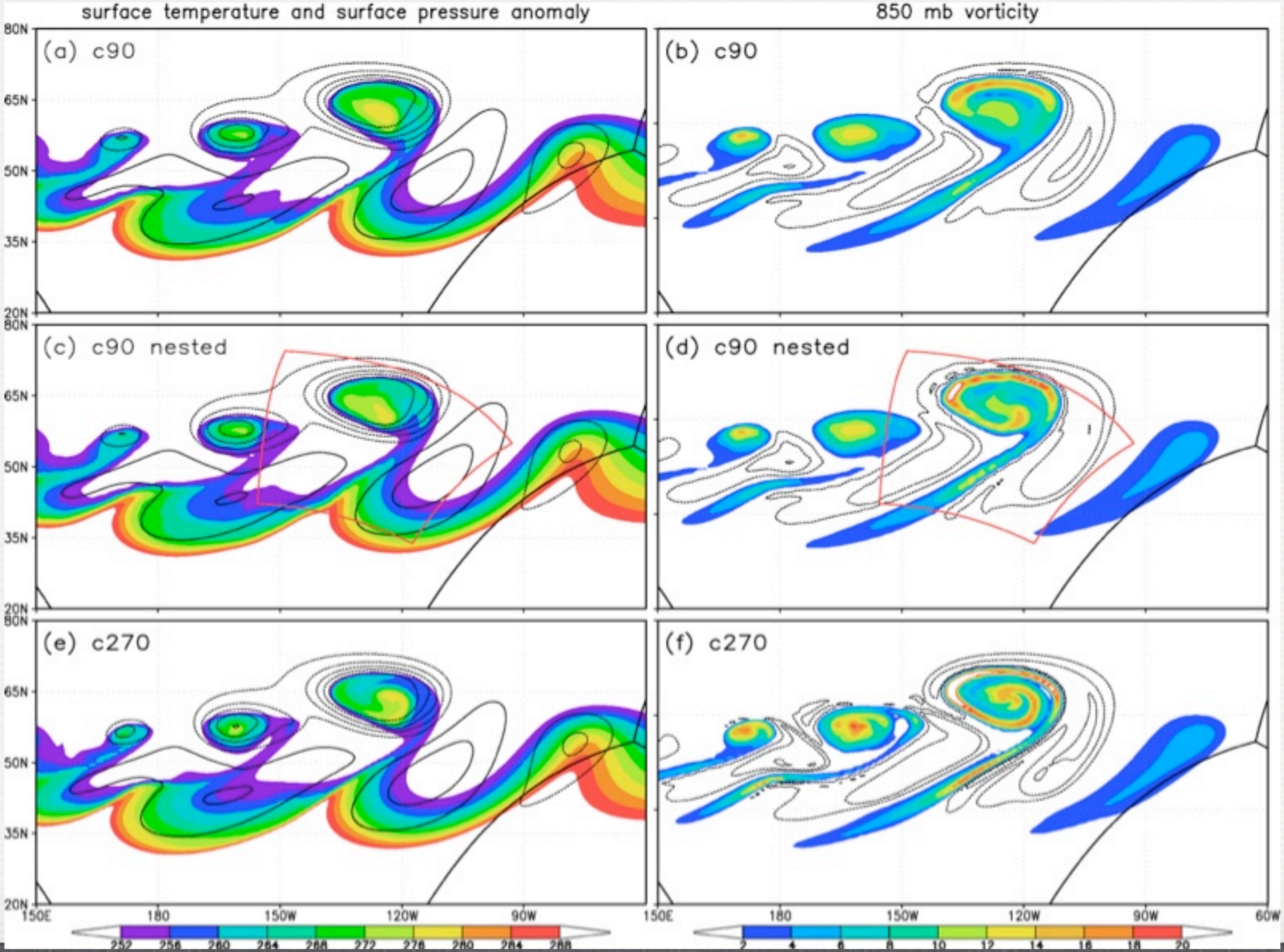
- Inserts a small, higher-resolution nested grid in global grid, with optional two-way feedback
  - Available in FV core

✓ Flexible sizes, numbers

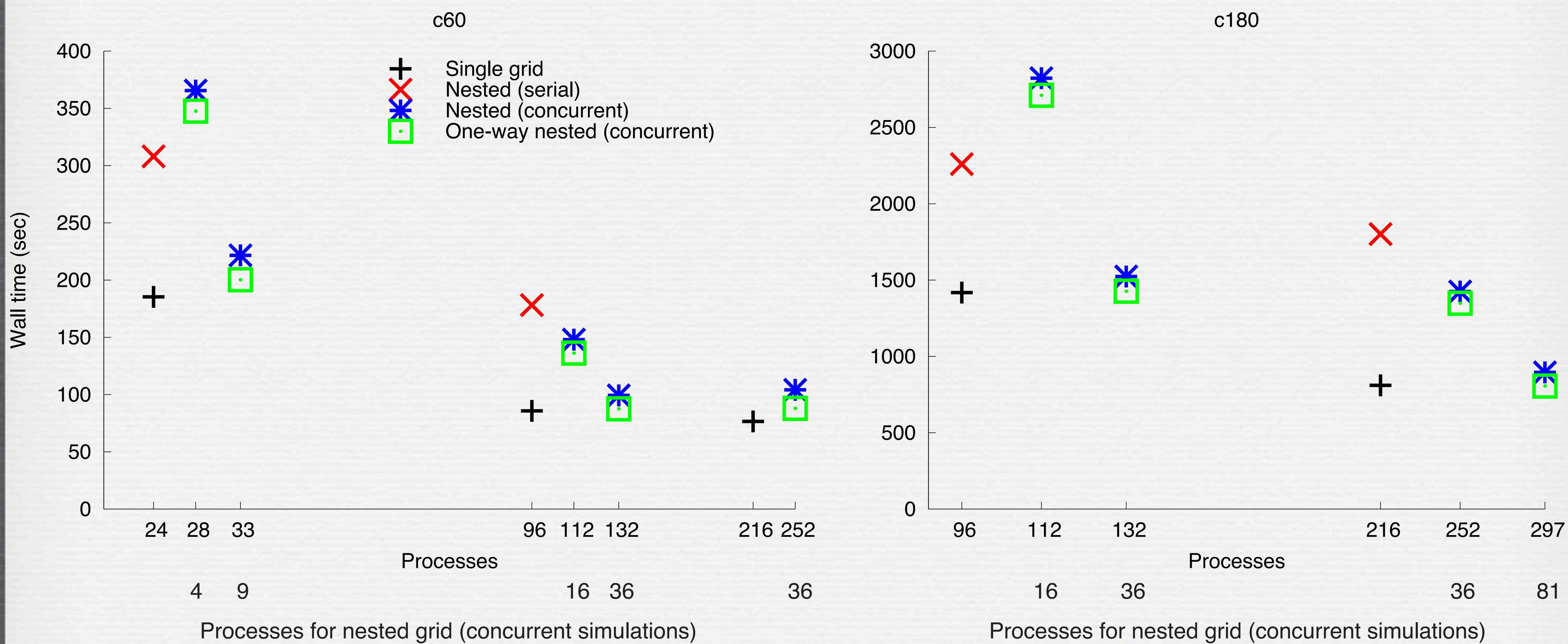
✗ Conservation is much harder

✗ Grid artifacts can be a problem

BAROCLINIC INSTABILITY TEST



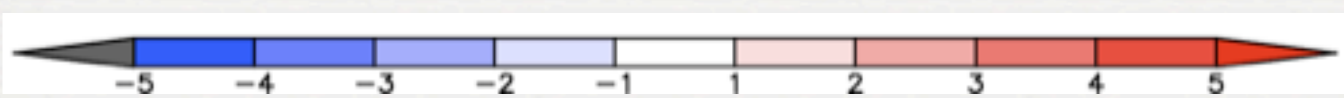
BC TEST: TIMING



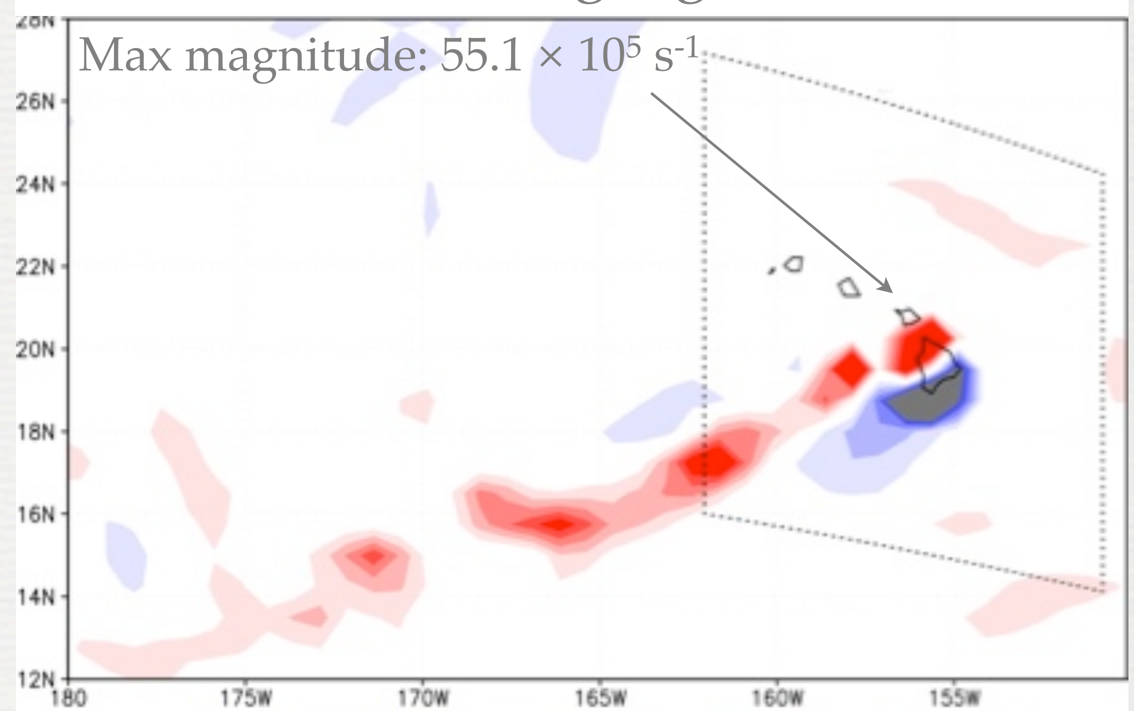
- In an environment with many available processors, using additional processors for concurrent nesting can yield large efficiency gains!

HAWAII LEE VORTICES

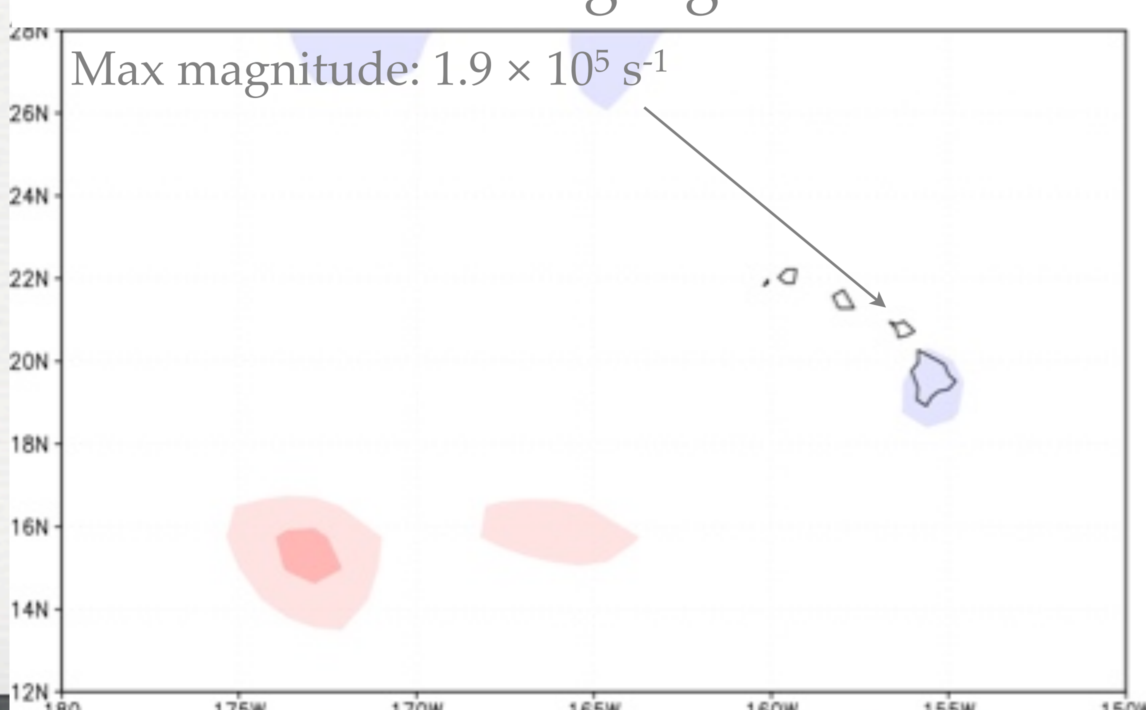
- 72 hr forecast from 1 Aug 2010 00Z with real topography
- Showing Vorticity × 10^5 s^{-1}, topping out at ±5



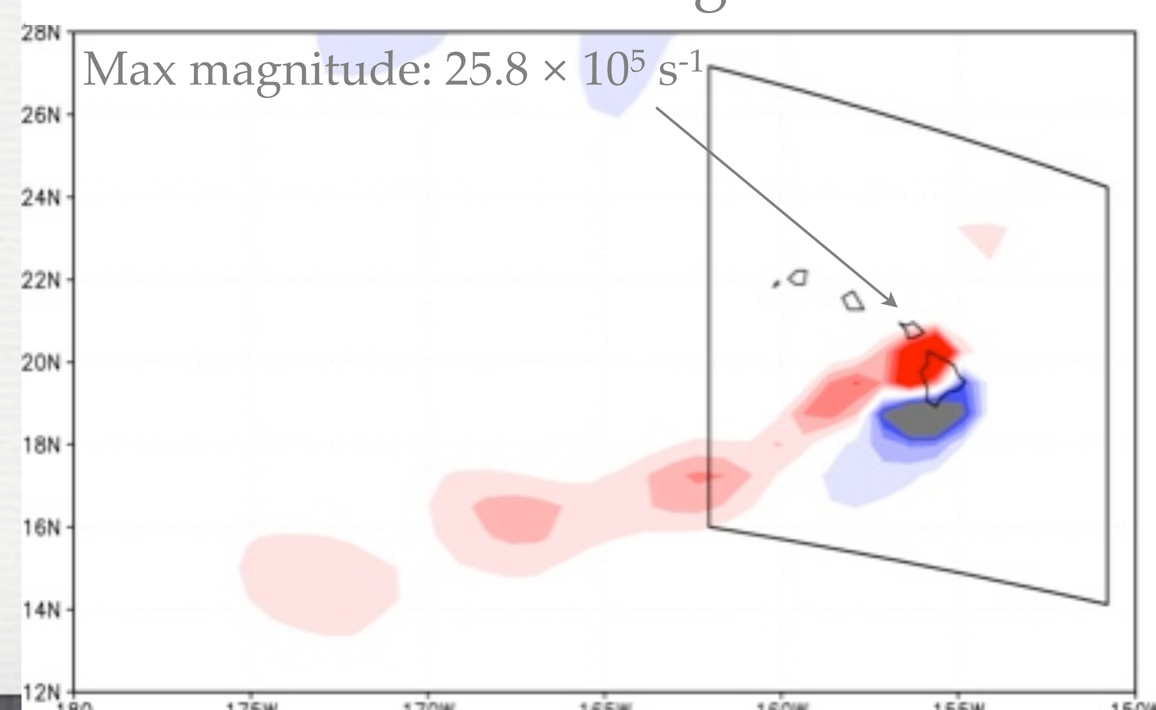
c360 single grid



c120 single grid

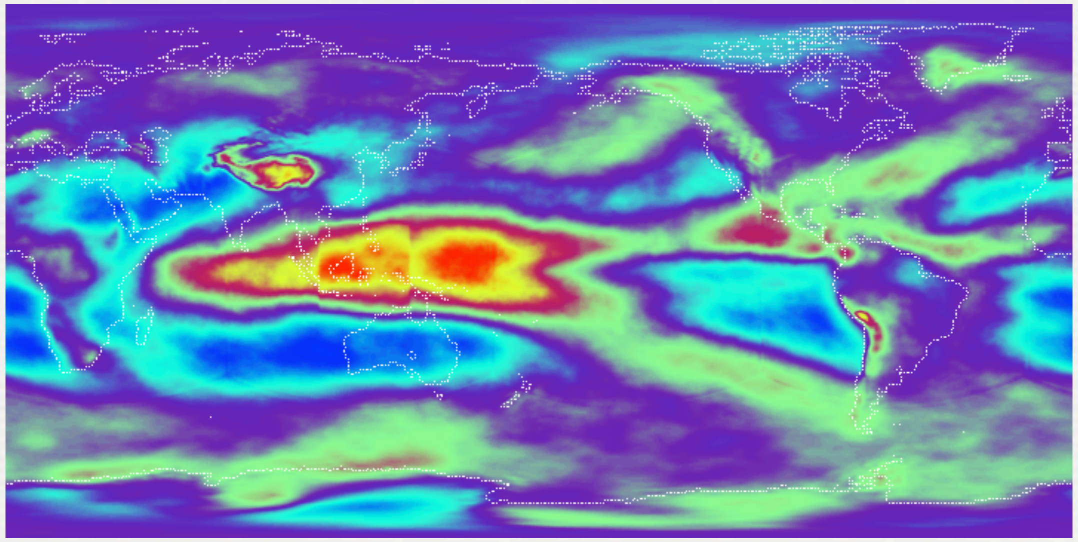


c120 nested grid

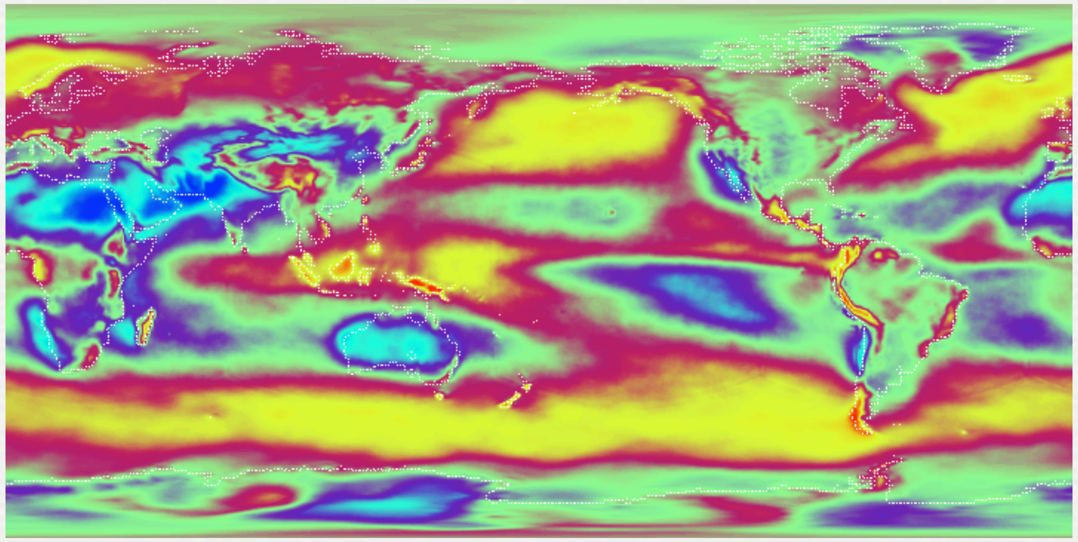


MARITIME CONTINENT C90 NESTED GRID

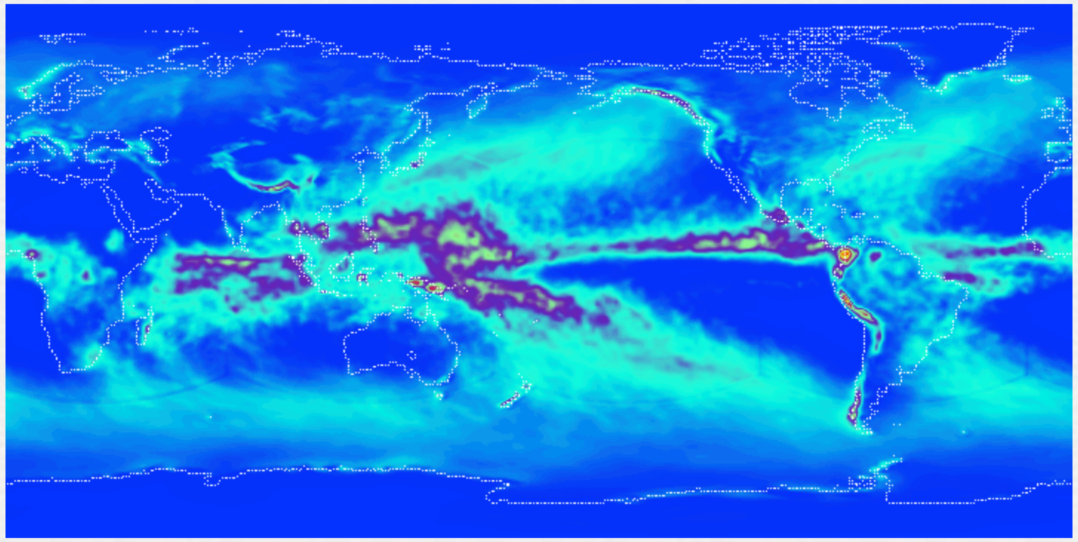
High cloud amount



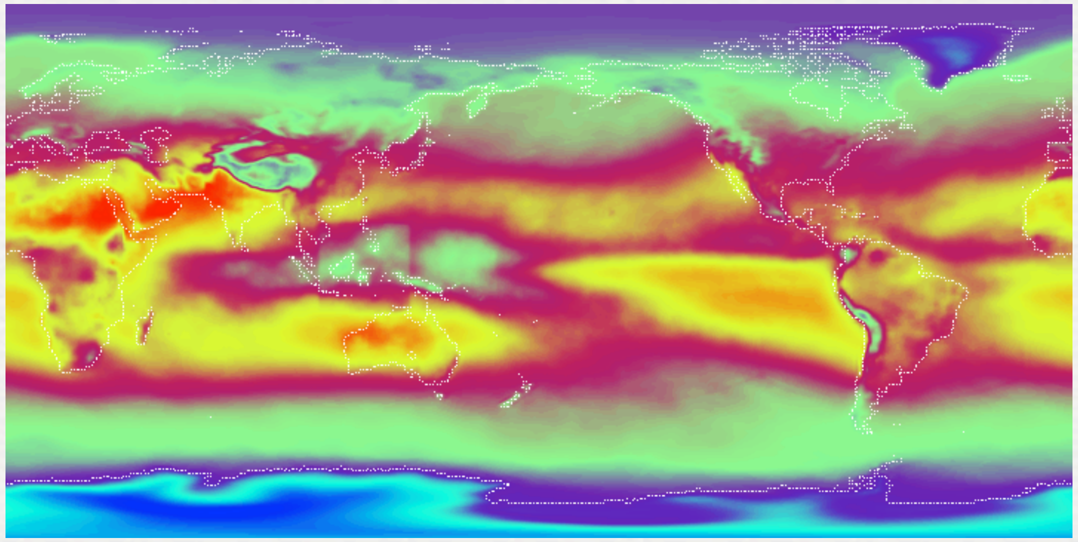
Total cloud amount



Precipitation

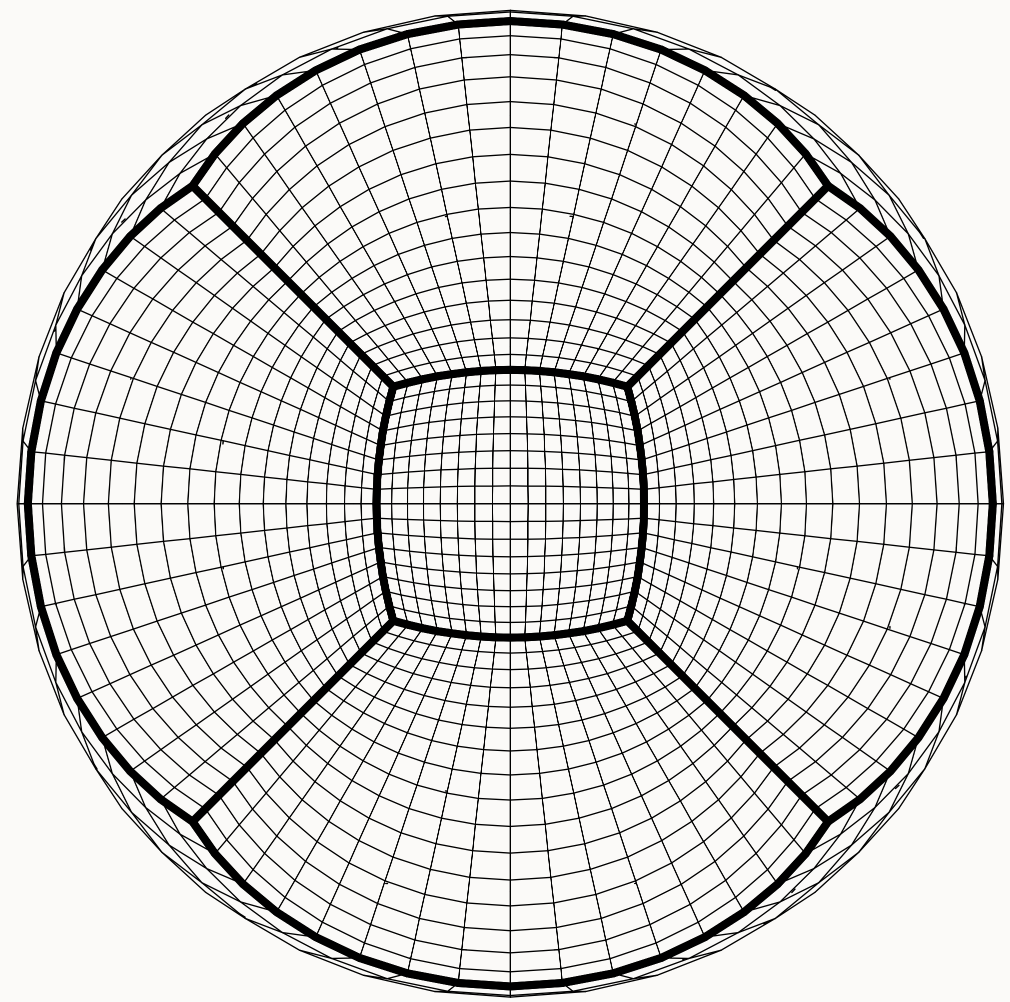


OLR



STRETCHED GRID

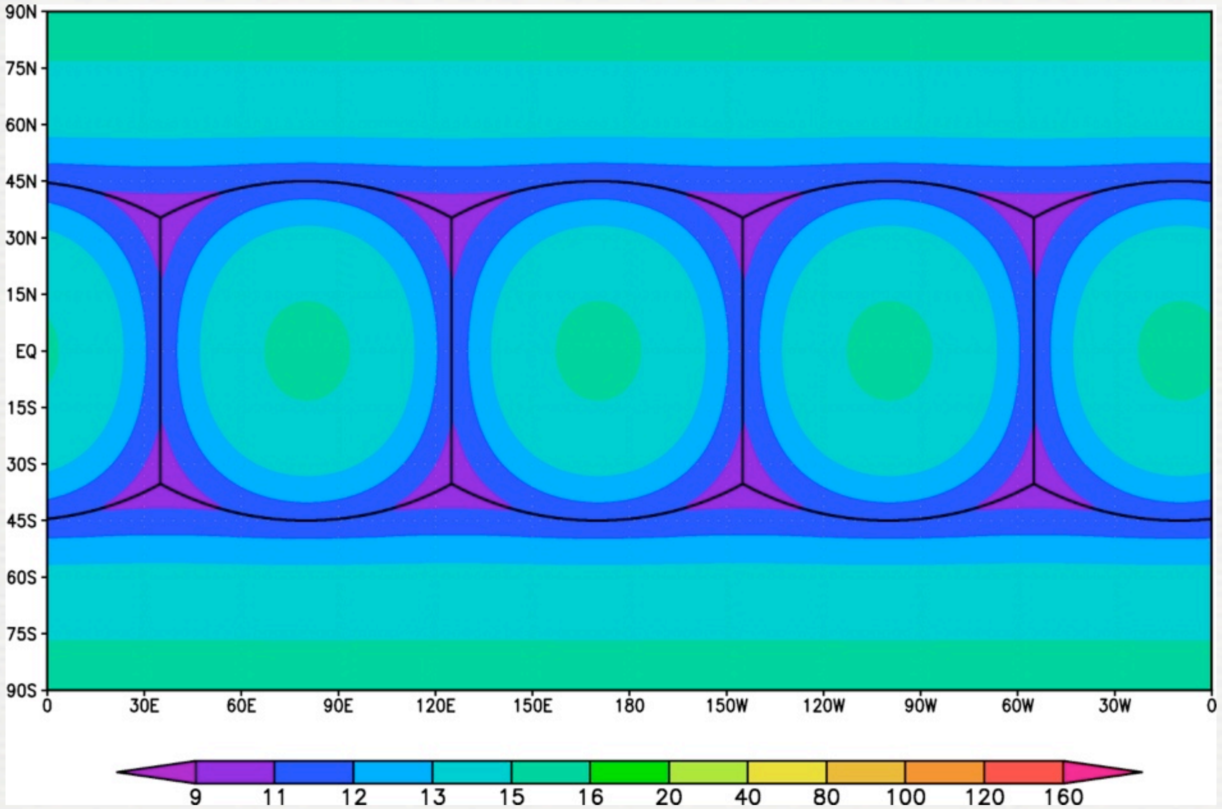
- Deforms cube into a truncated pyramid with one smaller face
  - Already in FV core
  - ✓ Slightly smoother than original cubed sphere
  - ✓ Automatically mass-conserving
  - ✗ Can only refine in one spot
  - ✗ Rest of solution degraded
  - ✗ Timestep restricted everywhere by smallest cell



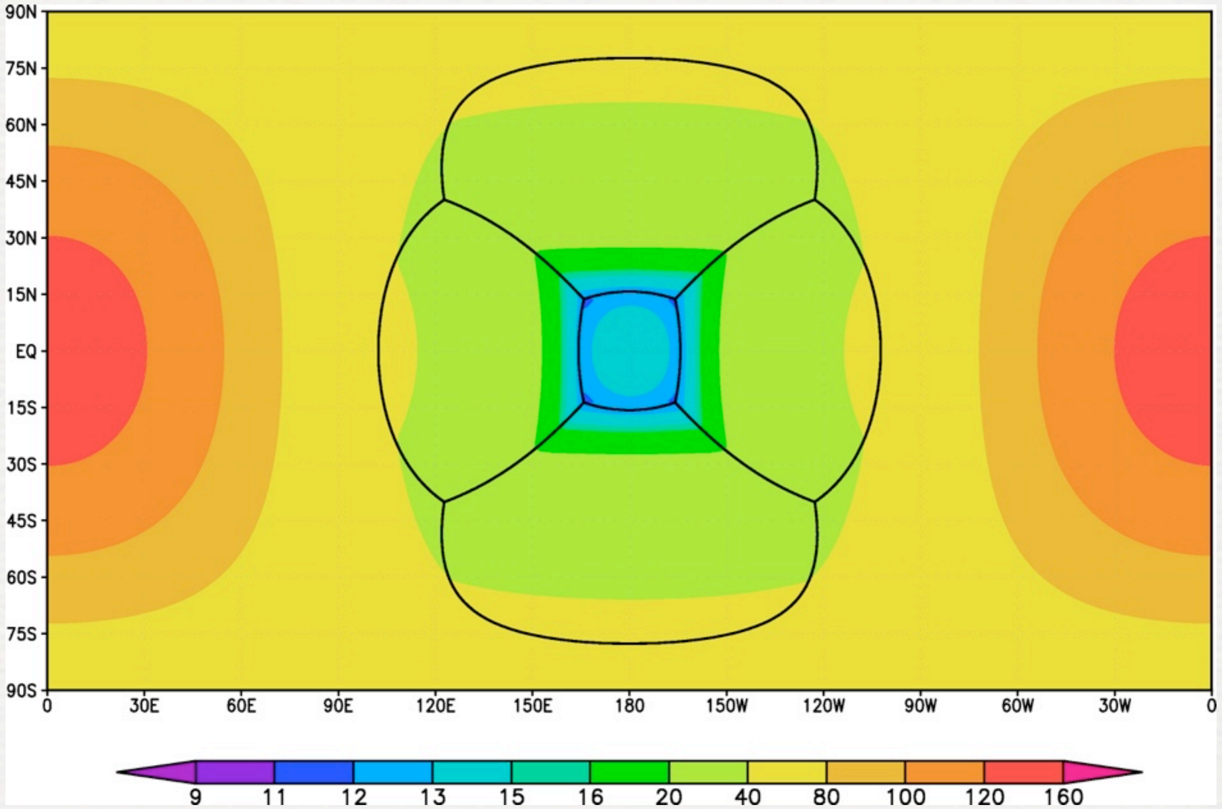
c16r3

$\Delta x_{avg} = 625$ km

c720

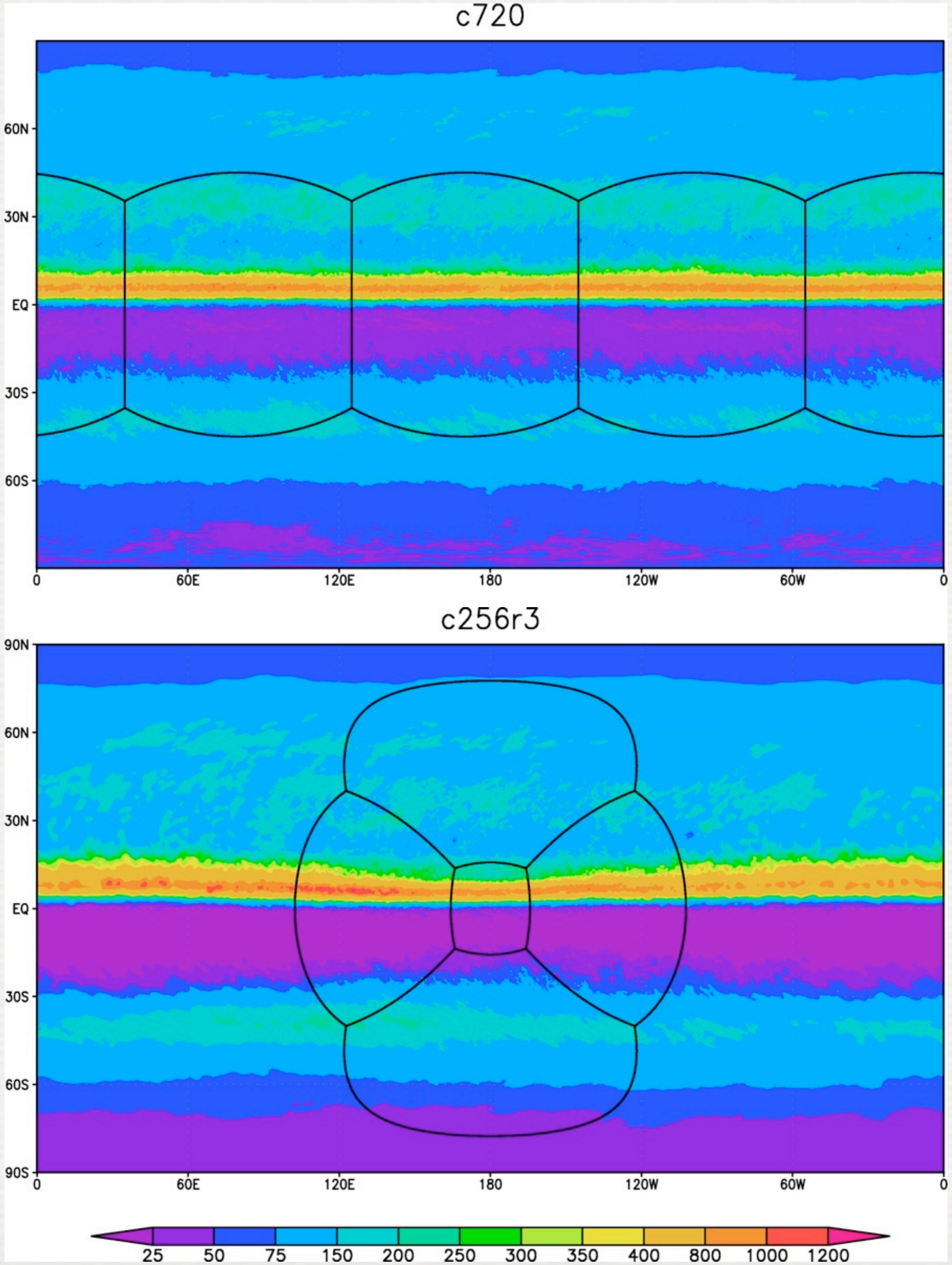


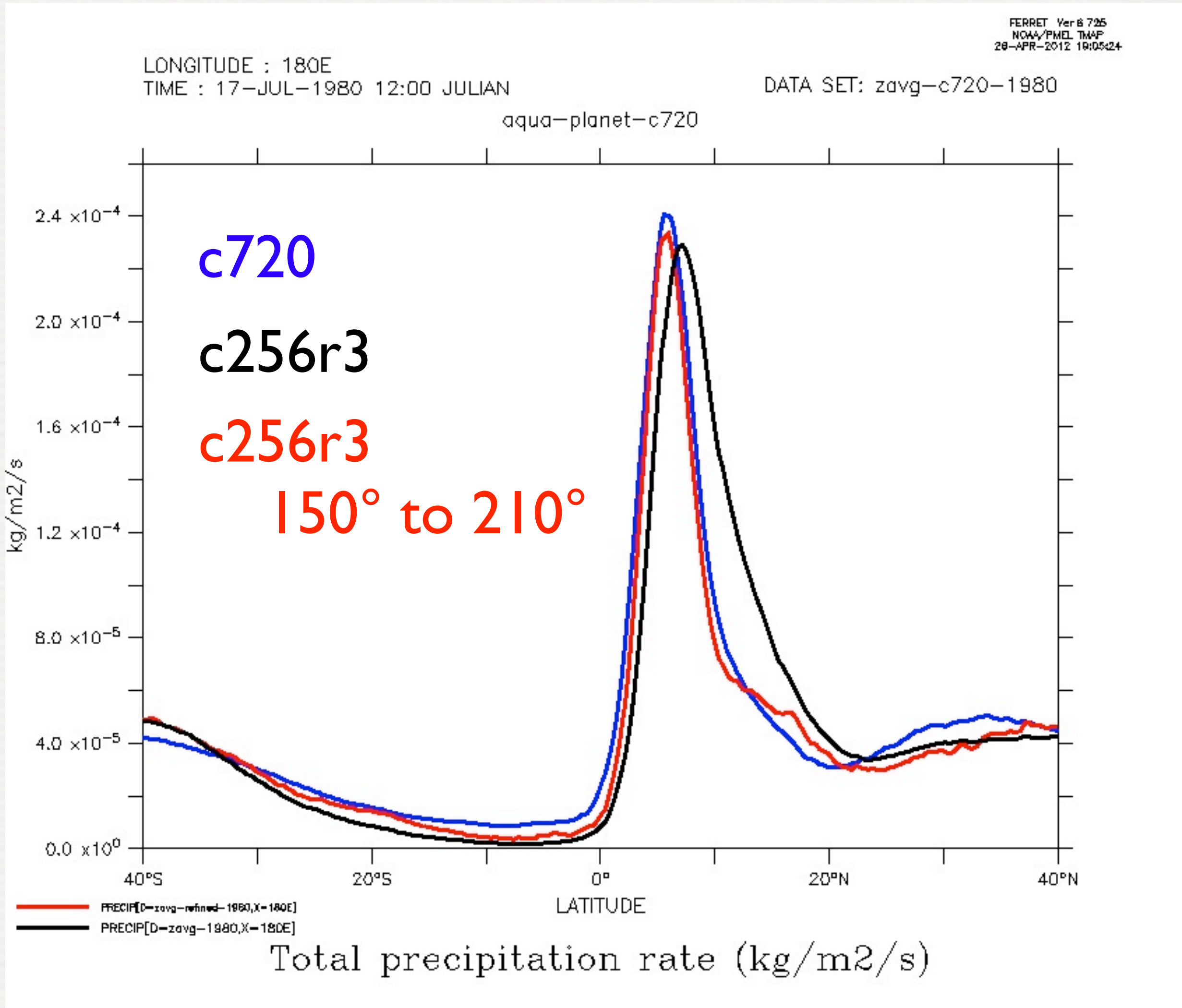
c256r3



	c720	c256r3
Δx avg	12.9 km	~ 40 km
Δx min	10.9 km	~ 13 km
Δx max	15.4 km	~ 117 km

AQUAPLANET: PRECIPITATION





AQUAPLANET: TROPICAL CYCLONES